RESEARCH

53(263), November 1, 2017

ISSN 2278–5469 EISSN 2278–5450

Discovery

# Estimation of chloride absorption in concrete cubes with finite moisture content

**Balakrishna MN[1☼], Fouad Mohamad[2], Robert Evans[2], Rahman MM[2]**

1.School of Architecture, Design and the Built Environment, Research scholar, Nottingham Trent University, Nottingham, NG1 4FQ, UK

2.School of Architecture, Design and the Built Environment, Faculty of Engineering, Nottingham Trent University, Nottingham, NG1 4FQ, UK

☼**Corresponding Author:**
School of Architecture,
Design and the Built Environment,
Research scholar, Nottingham Trent University,
Nottingham,
NG1 4FQ,
UK
Email: N0413461@my.ntu.ac.uk

**Article History**
Received: 10 August 2017
Accepted: 25 September 2017
Published: 1 November 2017

**Citation**
Balakrishna MN, Fouad Mohamad, Robert Evans, Rahman MM. Estimation of chloride absorption in concrete cubes with finite moisture content. *Discovery*, 2017, 53(263), 594-605



## ABSTRACT
The exposure of concrete infrastructures to chloride ions is the primary cause of premature corrosion of steel reinforcement. The intrusion of chloride ions, present in de-icing salts into reinforced concrete can cause steel corrosion if oxygen and moisture are also

available to sustain the reaction. In fact that, the chlorides dissolved in water can also permeate through sound concrete/reach the steel reinforcement through cracks. Therefore, there is a need to quantify the chloride absorption in concrete cubes which is of most important factor. The present research work was made an attempt to interpret the concrete chloride absorption in ordered to characterize the different concrete mixtures design for in case of pre-conditioned concrete cubes such as dry/fully/partially saturated condition which is salt ponded with chloride solution for about 160 days at 10% Nacl solution. Thus the objectives of this present research are such as, First, this research will examine the influence of conditioning such as dry/fully/partially saturated condition on the results of chloride absorption performed on concrete cubes with different mixtures proportion in which slump, and w/c ratio value was varied with constant compressive strength as in the First case and compressive strength, and w/c ratio value varied with constant slump as in the Second case. Seventy-two concrete cubes (100 $mm^3$) with Grades of concrete ranges from 25 to 40 $N/mm^2$ were prepared and evaluate the chloride absorption under different exposure condition. It's concluded from the results that, in dry/saturated conditioned concrete cubes, the chloride absorption value was increased in all designed mixtures type at longer time duration. Similarly, the average chloride absorption was decreased in solvent/water based impregnation DCC/PSC/FSC cubes as when compared to control DCC/PSC/FSC cubes for constant higher compressive strength and varied slump value as well as varied compressive strength and constant slump value. Whereas the average chloride absorption was increased in solvent/ water based impregnation DCC/PSC/FSC cubes for lesser compressive strength and constant slump value as when compared to constant higher compressive strength and varied slump value and the chloride absorption was goes on decreases with increased compressive strength and constant slump value.

**Keywords:** Concrete, Mixture proportion, Grade of concrete, Water-cement ratio, chloride absorption, moisture content, impregnation, and solvent/water based impregnate

## 1. INTRODUCTION

The concrete infrastructures such as bridge decks, parking garages, pre-stressed concrete structures, steel structures, and marine structures may deteriorate when they are exposed to de-icing agents. The de-icing agents can be absorbed into the pores of concrete and can modified the cementitious matrix structure. In fact that, the interaction between the de-icing agents and the cementitious matrix may result in the deterioration of concrete structures [1]. Physical damage can occur due to a number of processes such as exposure of concrete with a high degree of saturation to freeze-thaw cycles [2], scaling of concrete surfaces [3], crystallization of salt in concrete pores that results in production of an internal stress [4], and expansive forces as a result of corrosion of reinforcement when a chloride-based de-icing salt is used [5]. While the physical attack of de-icing salts has been widely investigated, the chemical reaction between the matrix and the de-icing salts has been investigated often less frequently. The use of de-icing salts can cause damage in cementitious materials even if a concrete does not experience freezing and melting [6]. This may be caused by the formation of Friedel's salt, Kuzel's salts [7], and/or calcium oxychloride, changes in the pore solution properties [8], or changes in the microstructure of hydration products [9]. De-icing salt solution, like many external solutions, may also dissolve calcium hydroxide, causing leaching that leads to an increase in permeability and a reduction of concrete alkalinity [10]. De-icing salts have different chemical and physical interactions with cementitious materials. The use of NaCl de-icing salt increases freeze-thaw damage in concrete. This increase in freeze-thaw damage has been explained by the formation of an unexpected phases and the creation of osmotic pressures [8]. Concrete exposed to $CaCl_2$ and $MgCl_2$ de-icing salts also exhibited changes in the concrete microstructure. These changes have been accompanied by a severe cracking and deterioration, even if the concrete did not experience any freeze-thaw cycles [7].

The concrete infrastructures were deteriorated in different regions of the world without satisfying the stipulated service life. Therefore there is a need to predict service life which is a major task in the design of concrete infrastructures. In fact, the chloride concentration is a major cause of any early deterioration of reinforced concrete infrastructures. As a result of this concrete deterioration, it may lead to cracking, spalling, and delamination of concrete cover, reduce load carrying capacity, and cross sectional area of reinforcement. Whereas, in the cold countries region it may lead to pre-mature deterioration of concrete infrastructures due to the application of deicing salts on roads and concrete infrastructures. In fact, the bridge-decks were simultaneously exposed to wetting drying condition and it's also subjected to direct impact as well as repeated loading by continuous flow of traffic. Almost all the concrete structures were working under dry conditions. Even though most of the researchers have dedicated their efforts to study transport of chloride in concrete under wet conditions with limited publication data on dry concrete. In fact major diffusion models are applicable to the concrete structures that remains fully wet condition at all the

times. They underestimate the amount of chloride penetrating a concrete structures which is subjected to wetting/drying for in case of splash/tidal zones of structures exposed to marine environment/highway structures exposed to de-icing salts. An experimental study is carried out on the influence of water absorption in ordered to evaluate the effectiveness of durability of concrete by researchers [11]. It's confirmed that, there is no clear relationship exists between surface sorptivity and internal sorptivity with compressive strength. It's also showed that, the surface water absorption is related to the performance of concrete which is includes permeability, sulfate attack, and chloride diffusion. Furthermore, it's possible to establish relationship between nonpermeability and resistance to sulfate attack which is linearly associated with surface sorptivity. An investigation by researchers [12] that, there is an influence of chloride absorption on concrete and interpret how this affects chloride distribution at different depths from the concrete surface. Results show that the surface chloride content, is very sensitive to effective porosity/drying conditions immediately before wetting. It also has as much as 31% of the protection provided by concrete cover can be lost after exposure to just one wet/dry cycle, and thereby significantly reducing time to corrosion of concrete structures. The research work carried out on the distribution of chloride at different depths, concrete pore structure, water/cementitious material ratio, cement type and percentage replacement of ground granulated blast furnace slag [13].

It's confirmed from results that the most significant effect of sorptivity on long-term chloride ingress to concrete is its effect on surface chloride content. It's decided to consider an effective amount of absorption when modelling chloride ingress under cyclic wetting and drying conditions. It's also possible from research work to produce higher surface chloride contents (0·29–0·62%) that would lower the time to corrosion using the cover depths recommended in the code. Its confirmed long time ago that [14], young and uncontaminated concrete can be surface impregnated by liquid silanes in order to provide a protective barrier against ingress of chloride ions and moderate chloride content allows to apply surface impregnation of silanes successfully as a protective measure as well as to avoid further chloride ingress. It's also confirmed that, higher chloride concentration and low water cement ratio make surface impregnation more difficult. Therefore it is recommended to test the efficiency of application of silane on concrete surfaces before a protective measure is carried out. It's confirmed that deep impregnation of the concrete surfaces with water repellent agent's forms an efficient and long lasting barrier with respect to chloride ingress [15]. In this way service life of reinforced concrete structures erected in an aggressive environment such as marine climate can be significantly extended for long time duration. It's cited by investigators [16-17] that, the corrosion of steel reinforcement induces expansion in volume due to corrosion products, cracking, and spalling of concrete from the reinforcement. Furthermore, chloride concentration together with frost attack can cause another form of concrete deterioration such as concrete scaling. As confirmed that [18], the pore space of concrete is not fully saturated. If the moisture content inside concrete is less than the saturation moisture content, it may be absorbed by the concrete through large capillary forces arising from the contact of the very small pores of the concrete with the liquid phase. Therefore, determination of the moisture retention function is necessary for the modelling of moisture flow and transport of chlorides in concrete. In fact, there has been very little effort to establish relationships for the capillary pressure as a function of degree of saturation for concrete. The chloride diffusion can only occur for a continuous water phase is present in the capillary pores of concrete in order to provide a path for diffusion. Therefore, in the case of dry concrete, the diffusion process is lessened since the number of water filled pores decreases and that decreases the continuity of pore solution [19]. Under dry conditions, the effective diffusion coefficient is no longer a constant but a function of saturation [20] and therefore cannot be described by simple diffusion theory.

This is noted by researchers that [21], hydrophobic treatment makes a concrete surface absorb lesser water and chloride. It's confirmed that, the corrosion which had already started before application of the hydrophobic agent was not influenced by hydrophobic treatment. No effect of hydrophobic treatment is measured on carbonation. It's also shown that, long term absorption tests with drinking and salt water showed significantly less absorption by hydrophobic concrete. Furthermore, its highlighted by researchers [22] that, hydrophobic agents could be effective for at least 10 years when applied to a 6-month-old concrete façade provide that, the concrete of the substrate needs to have a minimum age of 28 days or more. In addition to that, some conditions must be avoided when applying hydrophobic agents such as high or low temperatures, high air humidity and high construction element humidity. Therefore there is a need to investigate about the rapid deterioration of concrete structures due to reinforcement corrosion has now become a day-day growing problem in recent years at all over the world in so many cold countries region. Considerable resources are used to repair and rehabilitate deteriorated structures around the world. In addition to that, consequently, an extensive research [23] have been conducted to evaluate the effectiveness of sealers and other concrete surface treatment materials. Among the various procedures used to protect concrete surfaces, hydrophobic impregnations are the least harmful to essential concrete appearance, mainly inhibiting capillary water absorption of the concrete.

## 2. RESEARCH OBJECTIVES

The importance of chloride absorption as a durability-based material property has received greater attention only after the revelation that chloride-induced corrosion is the major problem for concrete durability. The present research work is made an attempt to interpret the concrete chloride absorption in ordered to characterize the different concrete mixtures design for in case of pre-conditioned concrete cubes such as dry/fully/partially saturated condition which is salt ponded with chloride solution for about 160 days. Thus the objectives of this present research is to examine the influence of conditioning such as dry/fully/partially saturated condition on the results of chloride absorption performed on concrete cubes with different mixtures proportion in which slump, and w/c ratio value was varied with constant compressive strength as in the First case and compressive strength, and w/c ratio value varied with constant slump as in the Second case. Seventy-two concrete cubes (100 mm$^3$) with Grades of concrete ranges from 25 to 40 N/mm$^2$ were prepared and evaluate the chloride absorption under different exposure condition at various drill depth (30-40-50) mm respectively.

## 3. EXPERIMENTAL PROGRAM

In the present research work, six different mixtures type were prepared in total as per BRE, 1988 [24] code standards with a concrete cubes of size (100 mm$^3$). Three of the mixtures type were concrete cubes (100 mm$^3$) with a compressive strength 40 N/mm$^2$, slump (0-10, 10-30, and 60-180 mm), and different w/c (0.45, 0.44, and 0.43). These mixtures were designated as M1, M2, and M3. Another Three of the mixtures type were concrete cubes with a compressive strength (25 N/mm$^2$, 30 N/mm$^2$, and 40 N/mm$^2$), slump (10-30 mm), and different w/c (0.5 0.45, and 0.44). These mixtures were designated as M4, M5, and M6. The overall details of the mixture proportions were to be represented in Table.1-2. Twelve concrete cubes of size (100 mm$^3$) were cast for each mixture and overall Seventy-two concrete cubes were casted for six types of concrete mixture. The coarse aggregate used was crushed stone with maximum nominal size of 10 mm with grade of cement 42.5 N/mm$^2$ and fine aggregate used was 4.75 mm sieve size down 600 microns for this research work. As concern to impregnation materials, Water based (WB) and Solvent based (SB) impregnate materials were used in this present research work. To avoid criticizing or promoting one particular brand of impregnation materials and for confidentiality reasons, the names of the products used will not be disclosed and they will be referred to as WB and SB respectively. WB is water borne acrylic co-polymer based impregnation material which is less hazardous and environmental friendly. It is silicone and solvent free and achieves a penetration of less than 10mm. SB consists of a colourless silane with an active content greater than 80% and can achieve penetration greater than 10 mm.

**Table 1** (Variable: Slump & W/C value; Constant: Compressive strength)

| **Mix No** | **Comp/mean target strength(N/mm$^2$)** | **Slump (mm)** | **w/c** | **C (Kg)** | **W (Kg)** | **FA (Kg)** | **CA(Kg) 10 mm** | **Mixture Proportions** |
|---|---|---|---|---|---|---|---|---|
| **M1** | 40/47.84 | 0-10 | 0.45 | 3.60 | 1.62 | 5.86 | 18.60 | 1:1.63:5.16 |
| **M2** | 40/47.84 | 10-30 | 0.44 | 4.35 | 1.92 | 5.62 | 16.88 | 1:1.29:3.87 |
| **M3** | 40/47.84 | 60-180 | 0.43 | 5.43 | 2.34 | 6.42 | 14.30 | 1:1.18:2.63 |

**Table 2** (Variable: Compressive strength & W/C value; Constant: Slump)

| **Mix No** | **Comp/mean target strength(N/mm$^2$)** | **Slump (mm)** | **w/c** | **C (Kg)** | **W (Kg)** | **FA (Kg)** | **CA(Kg) 10 mm** | **Mixture Proportions** |
|---|---|---|---|---|---|---|---|---|
| **M4** | 25/32.84 | 10-30 | 0.50 | 3.84 | 1.92 | 5.98 | 17.04 | 1:1.55:4.44 |
| **M5** | 30/37.84 | 10-30 | 0.45 | 4.27 | 1.92 | 6.09 | 16.50 | 1:1.42:3.86 |
| **M6** | 40/47.84 | 10-30 | 0.44 | 4.35 | 1.92 | 5.62 | 16.88 | 1:1.29:3.87 |

### 3.1. Salt Ponding Test

The chloride absorption test is carried out on concrete cubes of size (100 mm$^3$) and tested in accordance to BS 1881-122. They were water cured before subjected to the salt ponding test for about160 days. Before testing, the concrete specimens were oven dried to

constant mass at 105±5$^0$C for 72±2 hours and then stored in air-tight containers before subjected to testing. The concrete specimens are weighing before immersion and after immersion for specified time duration. For chloride absorption test, totally 18 concrete cubes is casted, out of which 6 control concrete cubes, 6 solvent based concrete cubes, and 6 water based concrete cubes. The chloride absorption test was carried out with 10% Nacl solution for about 160 days. The chloride absorption in dry conditioned concrete cubes is achieved by fully immersed in 10% Nacl solution as shown in Fig.1.


**Figure 1** Chloride absorption in DCC concrete cubes

The chloride absorption test with 10% Nacl solution is carried out on pre-conditioned fully saturated concrete cubes (Mc = 3%) of size (100 mm$^3$) which is fully submerged and noted their weights at each time duration for about 160 days. For chloride absorption test, totally 12 concrete cubes were casted, out of which 6 control concrete cubes, and 6 solvent based concrete cubes. The chloride absorption in partially saturated conditioned concrete cubes is achieved by immersed in 10% chloride solution as shown in Fig.2.


**Figure 2** Chloride absorption in FSC concrete cubes

The chloride absorption test with 10% Nacl solution was carried out on pre-conditioned partially saturated concrete cubes (Mc = 2%) of size (100 mm$^3$) which is fully submerged and noted their weights at each time duration for about 160 days. For chloride absorption test, totally 12 concrete cubes is casted, out of which 6 control concrete cubes, and 6 solvent based concrete cubes. The chloride absorption in partially saturated conditioned concrete cubes which is immersed in 10% Nacl solution as shown in Fig.3.


**Figure 3** Chloride absorption in PSC concrete cubes

In this research work, for chloride absorption test, totally 12 concrete cubes of size (100 $mm^3$) was casted as well as pre-conditioned to achieved moisture content (Mc = 2%), out of which 6 control concrete cubes, and 6 water based impregnation concrete cubes were used for this experimental work. The chloride absorption test is carried out with 10% Nacl solution which is fully submerged in order to achieve partially saturated condition (PSC) for about 160 days. In this research work, for chloride absorption test, totally 12 concrete cubes of size (100 $mm^3$) is casted as well as pre-conditioned to achieved moisture content (Mc = 3%), out of which 6 control concrete cubes, and 6 water based impregnation concrete cubes were used for this experimental work. The chloride absorption test is carried out with 10% Nacl solution which is fully submerged in order to achieve fully saturated condition (FSC) for about 160 days.

## 4. INTERPRETATION OF CHLORIDE ABSORPTION

The chloride penetration and moisture diffusion are two important transport processes for studying the long-term durability of concrete. The chloride penetration and moisture transfer in concrete are considered as two coupled transport processes. The interaction between moisture diffusion and chloride penetration in concrete affects the durability of reinforced concrete structures. The corrosion of the reinforcement in concrete takes place when the chloride content of concrete near steel bar has reached a threshold value and the moisture content in concrete is sufficiently high. Therefore, moisture and chloride ions are two necessary condition for the onset of corrosion of rebar in concrete. The diffusion of chloride and moisture in concrete can be studied for two different situations such as fully and partially saturated condition. In fist instance, the concrete is fully saturated, and dominant mechanisms for both chloride diffusion and moisture diffusion is the concentration gradient of chloride. In turn the chloride concentration gradient drives not only the chloride penetration but also the moisture movement in the concrete. In another instance, the concrete is partially saturated, and the moisture concentration gradient (in addition to the chloride concentration gradient) results in the moisture penetration as well as the chloride diffusion. In this case, both concentration gradients are driving forces. Thus in the present research work chloride absorption test was carried out on pre-conditioned concrete cubes (100 $mm^3$) such as dry/fully/partially saturated condition concrete cubes in order to evaluate the effectiveness of two impregnation materials namely solvent/water based impregnation material respectively. In turn its possible to interpret the effectiveness of impregnation (SB/WB) concrete cubes with control DCC/PSC/FSC concrete cubes for designed six mixtures type under pre-conditions with their variation in chloride absorption at different time duration as shown in Table.3-7 respectively.

**Table 3** Variation of chloride absorption in DCC concrete cubes

| Cube ID | Sodium chloride solution absorption in DCC concrete cubes | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Time, days | 31 | 61 | Incr (%) | 91 | Incr (%) | 121 | Incr (%) | 160 | Incr (%) |
| M1-0% | 0.134 | 0.269 | 50.44 | 0.968 | 86.21 | 1.892 | 92.94 | 2.43 | 94.51 |
| M2-0% | 0.122 | 0.335 | 63.70 | 1.072 | 88.65 | 1.902 | 93.61 | 2.13 | 94.28 |
| M3-0% | 0.119 | 0.283 | 57.90 | 1.026 | 88.40 | 1.886 | 93.69 | 2.14 | 94.43 |
| M4-0% | 0.118 | 0.226 | 47.97 | 0.967 | 87.85 | 1.909 | 93.84 | 1.96 | 94.00 |
| M5-0% | 0.111 | 0.251 | 55.79 | 1.041 | 89.33 | 1.873 | 94.07 | 1.94 | 94.27 |
| M6-0% | 0.124 | 0.295 | 58.05 | 0.964 | 87.16 | 1.829 | 93.23 | 1.79 | 93.07 |
| M1SB | 0.103 | 0.136 | 24.09 | 0.573 | 81.98 | 1.358 | 92.40 | 0.73 | 85.79 |
| M2SB | 0.102 | 0.136 | 25.38 | 0.565 | 82.01 | 1.376 | 92.62 | 0.73 | 86.18 |
| M3SB | 0.100 | 0.130 | 22.77 | 0.556 | 81.95 | 1.328 | 92.44 | 0.72 | 86.04 |
| M4SB | 0.105 | 0.139 | 24.32 | 0.594 | 82.33 | 1.331 | 92.12 | 0.73 | 85.57 |
| M5SB | 0.105 | 0.131 | 19.67 | 0.579 | 81.80 | 1.328 | 92.06 | 0.74 | 85.84 |
| M6SB | 0.104 | 0.153 | 31.62 | 0.576 | 81.87 | 1.325 | 92.12 | 0.72 | 85.57 |
| M1WB | 0.113 | 0.157 | 28.15 | 0.607 | 81.40 | 1.483 | 92.38 | 0.81 | 86.07 |
| M2WB | 0.107 | 0.142 | 24.84 | 0.565 | 81.08 | 1.398 | 92.35 | 0.76 | 85.86 |
| M3WB | 0.114 | 0.146 | 21.40 | 0.581 | 80.31 | 1.389 | 91.76 | 0.77 | 85.16 |
| M4WB | 0.109 | 0.156 | 30.36 | 0.598 | 81.82 | 1.347 | 91.93 | 0.79 | 86.21 |
| M5WB | 0.105 | 0.141 | 25.47 | 0.608 | 82.71 | 1.345 | 92.18 | 0.73 | 85.54 |
| M6WB | 0.114 | 0.139 | 17.98 | 0.604 | 81.15 | 1.331 | 91.45 | 0.73 | 84.50 |

**Table 4** Variation of chloride absorption in PSC concrete cubes

| Cube ID | Sodium chloride solution absorption in new PSC concrete cubes | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Time, days | 31 | 61 | Incr (%) | 91 | Incr (%) | 121 | Incr (%) | 160 | Incr (%) |
| M1-2% | 0.015 | 0.123 | 87.59 | 0.374 | 95.91 | 0.506 | 96.98 | 1.002 | 98.47 |
| M2-2% | 0.011 | 0.096 | 88.74 | 0.195 | 94.46 | 0.205 | 94.73 | 0.387 | 97.21 |
| M3-2% | 0.012 | 0.115 | 89.96 | 0.298 | 96.12 | 0.301 | 96.15 | 0.690 | 98.32 |
| M4-2% | 0.010 | 0.094 | 89.06 | 0.187 | 94.54 | 0.204 | 94.99 | 0.283 | 96.39 |
| M5-2% | 0.013 | 0.125 | 89.37 | 0.202 | 93.44 | 0.212 | 93.72 | 0.664 | 98.00 |
| M6-2% | 0.011 | 0.093 | 88.67 | 0.159 | 93.39 | 0.170 | 93.82 | 0.258 | 95.92 |
| M1SB | 0.011 | 0.123 | 91.18 | 0.199 | 94.53 | 0.209 | 94.80 | 0.556 | 98.05 |
| M2SB | 0.010 | 0.093 | 88.84 | 0.142 | 92.68 | 0.147 | 92.97 | 0.227 | 95.44 |
| M3SB | 0.011 | 0.110 | 90.20 | 0.185 | 94.15 | 0.192 | 94.36 | 0.485 | 97.77 |
| M4SB | 0.010 | 0.081 | 87.24 | 0.141 | 92.68 | 0.143 | 92.77 | 0.215 | 95.19 |
| M5SB | 0.011 | 0.108 | 90.10 | 0.182 | 94.14 | 0.187 | 94.32 | 0.430 | 97.53 |
| M6SB | 0.010 | 0.036 | 71.2598 | 0.129 | 92.02 | 0.136 | 92.44 | 0.210 | 95.10 |

**Table 5** Variation of chloride absorption in FSC concrete cubes

| Cube ID | Sodium chloride solution absorption in new FSC concrete cubes | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Time, days | 31 | 61 | Incr (%) | 91 | Incr (%) | 121 | Incr (%) | 160 | Incr (%) |
| M1-3% | 0.0051 | 0.0490 | 89.59 | 0.129 | 96.05 | 0.2612 | 98.05 | 0.685 | 99.26 |
| M2-3% | 0.0044 | 0.0250 | 82.45 | 0.092 | 95.24 | 0.1347 | 96.75 | 0.224 | 98.04 |
| M3-3% | 0.0044 | 0.0453 | 90.33 | 0.118 | 96.30 | 0.1874 | 97.66 | 0.489 | 99.10 |
| M4-3% | 0.0036 | 0.0233 | 84.53 | 0.09 | 95.99 | 0.1346 | 97.32 | 0.222 | 98.38 |
| M5-3% | 0.0038 | 0.0433 | 91.20 | 0.099 | 96.14 | 0.1833 | 97.92 | 0.478 | 99.20 |
| M6-3% | 0.0034 | 0.0230 | 85.03 | 0.078 | 95.57 | 0.1201 | 97.13 | 0.209 | 98.36 |
| M1SB | 0.0035 | 0.0379 | 90.69 | 0.091 | 96.12 | 0.1266 | 97.21 | 0.394 | 99.10 |
| M2SB | 0.0032 | 0.0215 | 85.08 | 0.077 | 95.84 | 0.0796 | 95.97 | 0.214 | 98.50 |
| M3SB | 0.0033 | 0.0252 | 86.77 | 0.066 | 94.98 | 0.1240 | 97.32 | 0.337 | 99.01 |
| M4SB | 0.0028 | 0.0199 | 85.9 | 0.030 | 90.75 | 0.0793 | 96.46 | 0.175 | 98.40 |
| M5SB | 0.0024 | 0.0232 | 89.6901 | 0.031 | 92.15 | 0.0399 | 94.00 | 0.123 | 98.05 |
| M6SB | 0.0019 | 0.0150 | 87.33 | 0.018 | 89.27 | 0.0201 | 90.55 | 0.111 | 98.29 |

**Table 6** Variation of chloride absorption in PSC concrete cubes

| Cube ID | Sodium chloride solution absorption in PSC concrete cubes | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Time, days | 31 | 61 | Incr (%) | 91 | Incr (%) | 121 | Incr (%) | 160 | Incr (%) |
| M1-2% | 0.0086 | 0.0092 | 7.04 | 0.0148 | 41.86 | 0.3317 | 97.41 | 1.110 | 99.23 |
| M2-2% | 0.0076 | 0.0085 | 10.53 | 0.0101 | 24.94 | 0.0904 | 91.59 | 0.430 | 98.23 |
| M3-2% | 0.0080 | 0.0087 | 8.21 | 0.0137 | 41.53 | 0.2089 | 96.15 | 0.741 | 98.92 |
| M4-2% | 0.0076 | 0.0082 | 7.48 | 0.0091 | 16.83 | 0.0685 | 88.96 | 0.313 | 97.58 |
| M5-2% | 0.0078 | 0.0081 | 4.58 | 0.0102 | 24.24 | 0.1778 | 95.64 | 0.682 | 98.86 |
| M6-2% | 0.0076 | 0.0080 | 4.86 | 0.0086 | 11.28 | 0.0633 | 87.96 | 0.271 | 97.18 |
| M1WB | 0.0087 | 0.0090 | 2.98 | 0.0097 | 9.92 | 0.1530 | 94.28 | 0.572 | 98.47 |
| M2WB | 0.0076 | 0.0084 | 9.97 | 0.0092 | 17.54 | 0.0912 | 91.68 | 0.253 | 97.00 |
| M3WB | 0.0080 | 0.0087 | 8.83 | 0.0095 | 15.75 | 0.1108 | 92.80 | 0.521 | 98.47 |
| M4WB | 0.0073 | 0.0083 | 11.39 | 0.0088 | 16.52 | 0.0529 | 86.14 | 0.241 | 96.96 |
| M5WB | 0.0076 | 0.0082 | 8.03 | 0.0093 | 18.85 | 0.0793 | 90.43 | 0.466 | 98.37 |
| M6WB | 0.0071 | 0.0075 | 4.85 | 0.008 | 10.96 | 0.0384 | 81.51 | 0.232 | 96.95 |

**Table 7** Variation of chloride absorption in FSC concrete cubes

| Cube ID | Sodium chloride solution absorption in FSC concrete cubes | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Time, days | 31 | 61 | Incr (%) | 91 | Incr (%) | 121 | Incr (%) | 160 | Incr (%) |
| M1-3% | 0.0066 | 0.0117 | 43.38 | 0.2298 | 97.11 | 0.3325 | 98.00 | 0.706 | 99.06 |
| M2-3% | 0.0051 | 0.0097 | 47.89 | 0.0756 | 93.30 | 0.1282 | 96.05 | 0.238 | 97.88 |
| M3-3% | 0.0050 | 0.0122 | 58.78 | 0.2222 | 97.74 | 0.3095 | 98.38 | 0.502 | 99.00 |
| M4-3% | 0.0041 | 0.0062 | 33.57 | 0.1029 | 95.97 | 0.1287 | 96.78 | 0.236 | 98.24 |
| M5-3% | 0.0052 | 0.0117 | 55.67 | 0.1267 | 95.92 | 0.2492 | 97.93 | 0.495 | 98.95 |
| M6-3% | 0.0026 | 0.0079 | 67.45 | 0.0779 | 96.69 | 0.1727 | 98.51 | 0.211 | 98.78 |
| M1WB | 0.0048 | 0.0100 | 52.08 | 0.1126 | 95.76 | 0.2535 | 98.12 | 0.496 | 99.04 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| M2WB | 0.0029 | 0.0080 | 63.38 | 0.0355 | 91.81 | 0.1230 | 97.63 | 0.219 | 98.67 |
| M3WB | 0.0046 | 0.0057 | 19.34 | 0.0966 | 95.22 | 0.2259 | 97.96 | 0.352 | 98.69 |
| M4WB | 0.0025 | 0.0031 | 20.34 | 0.0363 | 93.21 | 0.1140 | 97.84 | 0.179 | 98.63 |
| M5WB | 0.0038 | 0.0045 | 16.45 | 0.0553 | 93.15 | 0.1186 | 96.81 | 0.166 | 97.72 |
| M6WB | 0.0021 | 0.0026 | 17.06 | 0.0486 | 95.62 | 0.0860 | 97.53 | 0.129 | 98.36 |

## 5. DISCUSSION ABOUT RESULTS

Thus in the present research work chloride absorption test was carried out on pre-conditioned concrete cubes (100 $mm^3$) such as dry/fully/partially saturated conditioned concrete cubes in order to evaluate the effectiveness of two impregnation materials namely solvent/water based impregnation material respectively. It's observed from results that (DCC concrete cubes) for higher compressive strength and varied slump value, the chloride absorption was found to be slightly higher in magnitude as when compared to solvent based and water based impregnation concrete cubes for in case of mixtures type (M1-M3). Also its observed from the results that, for lower compressive strength and constant slump value, the chloride absorption was found to be slightly more as when compared to higher compressive strength for in case of mixtures type (M5-M6) as shown in Fig.4.

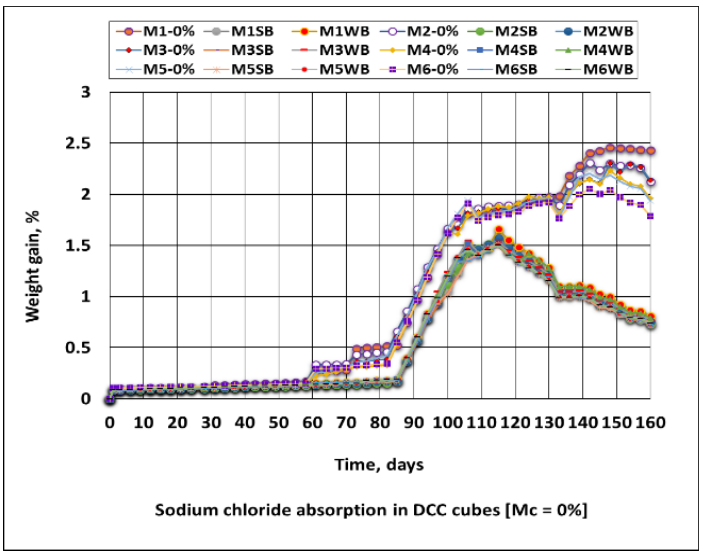


**Figure 4** Chloride absorption in DCC concrete cubes

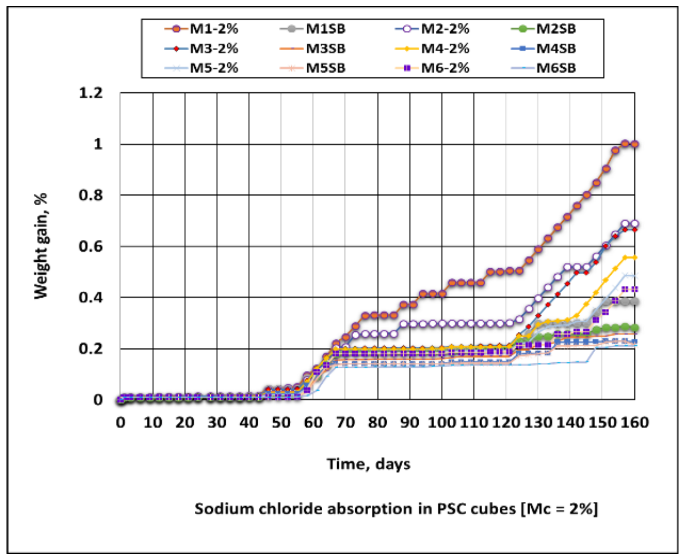


**Figure 5** Chloride absorption in PSC concrete cubes

The average chloride absorption for in case of DCC concrete cubes is increased at 61th, 91th, 121th, and 160th days as when compared to 31th day which could in the range varied (60th -31th day) as in control concrete cubes, solvent based impregnation concrete cubes, and water based impregnation concrete cubes in mixtures type (M1-M6) respectively. In the same way the chloride absorption was decreased in solvent based impregnation concrete cubes as when compared to water based impregnation concrete cubes. It's also observed from results that (PSC concrete cubes) for higher compressive strength and varied slump value, the chloride absorption was found to be slightly higher in magnitude as when compared to solvent based and water based impregnation concrete cubes for in case of mixtures type (M1-M3) as observed from Fig.5. Also its observed from the results that, for lower compressive strength and constant slump value, the chloride absorption was found to be slightly more as when compared to higher compressive strength for in case of mixtures type (M5-M6). The average chloride absorption was increased at 61th, 91th, 121th, and 160th days as when compared to 31th day which could in the range varied (60th -31th day) as in control concrete cubes, solvent based impregnation concrete cubes, and water based impregnation concrete cubes in (M1-M6). The chloride absorption was increased in control concrete cubes as when compared to solvent based impregnation concrete cubes. In the same way the chloride absorption was decreased in solvent based impregnation concrete cubes as when compared to control concrete cubes. It's clear from results that (FSC concrete cubes) for higher compressive strength and varied slump value, the chloride absorption was found to be slightly higher in magnitude as when compared to solvent based and water based impregnation concrete cubes for in case of mixtures type

(M1-M3) as confirmed from Fig.6. Also its observed from the results that, for lower compressive strength and constant slump value, the chloride absorption was found to be slightly more as when compared to higher compressive strength for in case of mixtures type (M5-M6).The average chloride absorption was increased at 61$^{th}$, 91$^{th}$, 121$^{th}$, and 160$^{th}$ days as when compared to 31$^{th}$ day which could in the range varied (61$^{th}$ -31$^{th}$ day) as in control concrete cubes, and solvent based impregnation concrete cubes. The chloride absorption was increased in control concrete cubes as when compared to solvent based impregnation concrete cubes. In the same way the chloride absorption was decreased in solvent based impregnation concrete cubes as when compared to control concrete cubes.

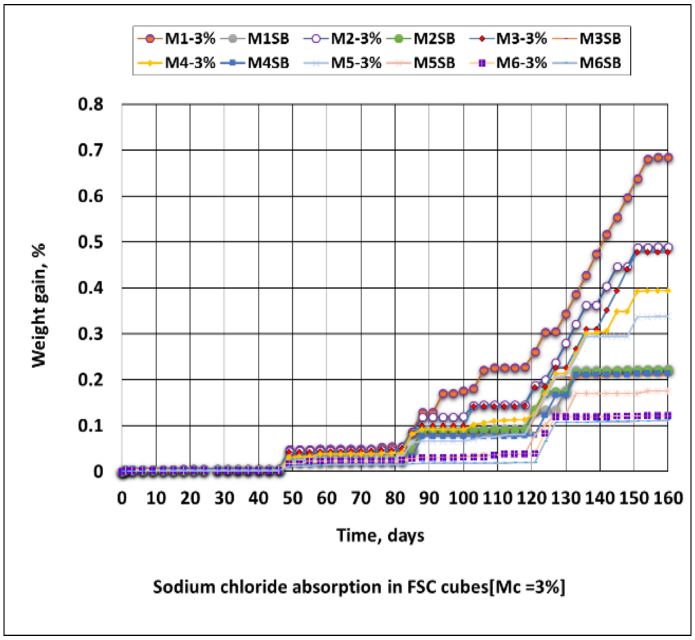


**Figure 6** Chloride absorption in FSC concrete cubes

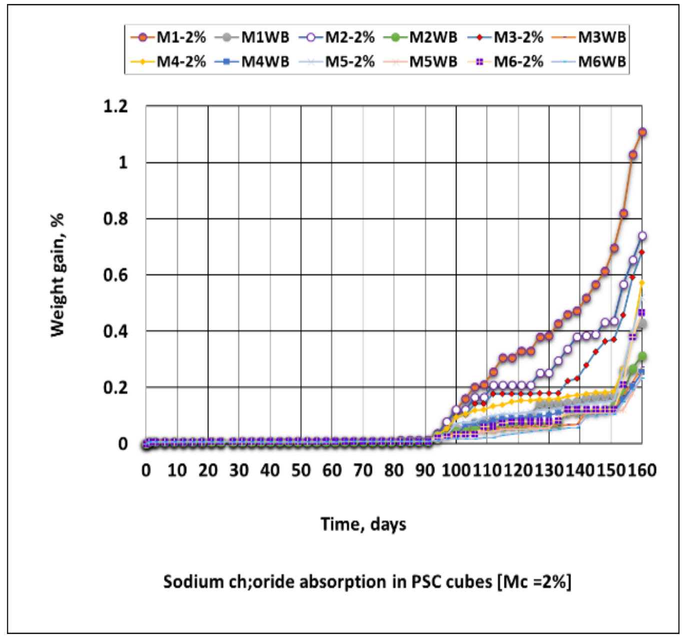


**Figure 7** Chloride absorption in PSC concrete cubes

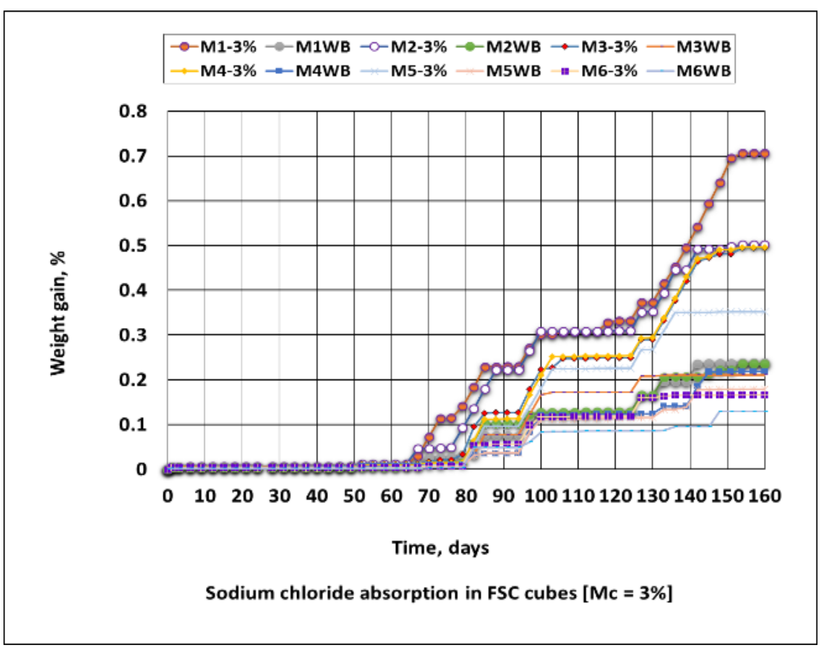


**Figure 8** Chloride absorption in FSC concrete cubes

It's interpreted from the results that (Mc = 2%, SB)) for higher compressive strength and varied slump value, the chloride absorption was found to be slightly higher in magnitude as when compared to water based impregnation concrete cubes for in case of mixtures type (M1-M3) as clear from the Fig.7. Also its observed from the results that, for lower compressive strength and constant slump value, the chloride absorption was found to be slightly more/less as when compared to higher compressive strength for in case of mixtures type (M5-M6). The average chloride absorption was increased at 61$^{th}$, 91$^{th}$, 121$^{th}$, and 160$^{th}$ days as when compared to 31$^{th}$ day which could in the range varied (60$^{th}$ -31$^{th}$day) as in control concrete cubes, and water based impregnation concrete cubes. The chloride absorption was increased in control concrete cubes as when compared to water based impregnation concrete cubes. In the other way the chloride absorption was decreased in water based impregnation concrete cubes as when compared to control concrete cubes. It's interpreted from the results that (Mc =3%, WB) for higher compressive strength and varied slump value, the chloride absorption was found to be slightly higher in magnitude as when compared to water based impregnation concrete cubes for in case of mixtures type (M1-M3) as concluded from the Fig.8. Also its observed from the results that, for lower compressive strength and constant slump value, the chloride absorption was found to be slightly more/less as when compared to higher compressive strength for in case of mixtures type (M5-M6). The average chloride absorption was increased at 61$^{th}$, 91$^{th}$, 121$^{th}$, and 160$^{th}$ days as when compared to 31$^{th}$ day which could in the range varied (60$^{th}$ -31$^{th}$ day) as in control concrete cubes, and water based impregnation concrete cubes. The chloride absorption was increased in control concrete cubes as when compared to water based impregnation concrete cubes. In the other way the chloride absorption was decreased in water based impregnation concrete cubes as when compared to control concrete cubes.

## 6. CONCLUSIONS

The chloride penetration and moisture diffusion are two most important transport properties for responsible for the long-term durability of concrete structure. The chloride penetration and moisture transfer in concrete are considered as the two coupled transport processes. The interaction between moisture diffusion and chloride penetration in concrete affects the durability of reinforced concrete structures.

- Thus in the present research work chloride absorption test was carried out on 66 pre-conditioned concrete cubes (100x100x100) mm such as dry/fully/partially saturated conditioned concrete cubes in order to evaluate the effectiveness of two impregnation materials namely solvent based and water based impregnation material respectively. In turn to interpret the effectiveness of impregnation concrete cubes
- with control cubes for six mixtures type under pre-conditioned concrete cubes with constant compressive strength (40 N/mm$^2$), and varied slump (0-10, 10-30, 60-180) mm in one case as well as varied compressive strength (25-30-40 N/mm$^2$) with constant slump (10-30) mm in second case.
- Finally to produce Sorptivity values for in case of concrete cubes with differential desired moisture content (Mc =2%, and Mc =3%) which was fully submerged in salt solution with/without impregnation.
- It's observed from results that, the chloride absorption in DCC-Mc-0% control concrete cubes was increased as when compared to PSC-Mc-2%, and PSC (SB)-Mc-2% concrete cubes. It's also observed from results that, the chloride absorption in DCC(WB)-Mc-0% impregnation concrete cubes was increased in six all mixtures type as when compared to PSC(WB)-Mc-2% concrete cubes.

It's observed from results that, the chloride absorption in DCC-Mc-0% control concrete cubes was increased as when compared to FSC-Mc-3% concrete cubes. It's also confirmed from results that, the chloride absorption in DCC (SB)-Mc-0% and DCC (WB)-Mc-0% impregnation concrete cubes was increased as when compared to FSC (SB)-Mc-3% as well as FSC (WB)-Mc-3% concrete cubes. It's observed from results that, the chloride absorption in FSC-Mc-3% control concrete cubes was increased in six all mixtures type as when compared to PSC-Mc-2% concrete cubes.

## REFERENCE


1. W. Jones, Y. Farnam, P. Imbrock, J. Sprio, C. Villani, J. Olek, et al., An Overview of Joint Deterioration in Concrete Pavement:Mechanisms, Solution Properties, and Sealers, 2013. doi:10.5703/1288284315339.
2. W. Li, M. Pour-Ghaz, J. Castro, J. Weiss, Water absorption and critical degree of saturation relating to freeze-thaw damage in concrete pavement joints, J. Mater. Civ. Eng. 24 (2012) 299–307. doi:10.1061/(ASCE)MT.1943-5533.0000383.
3. S. Jacobsen, D. Sœther, E. Sellevold, Frost testing of high strength concrete: Frost/salt scaling at different cooling rates, Mater. Struct. 30 (1997) 33–42. http://link.springer.com/article/10.1007/BF02498738 (accessed April 09, 2013).
4. G. Scherer, Crystallization in pores, Cem. Concr. Res. 29 (1999) 1347–1358. doi:http://dx.doi.org/10.1016/S0008-8846(99)00002-2.

5. Z. Wang, Q. Zeng, L. Wang, Y. Yao, K. Li, Corrosion of rebar in concrete under cyclic freeze–thaw and Chloride salt action, Constr. Build. Mater. 53 (2014) 40–47. doi:10.1016/j.conbuildmat.2013.11.063.
6. J. Marchand, E.J. Sellevold, M. Pigeon, The De-icer Salt Scaling Deterioration of Concrete - An Overview, in: V.M. Malhotra (Ed.), Third Int. Conf. Durab. Concr., Nice, France., 1994: pp. 1–46.
7. M. Collepardi, L. Coppola, C. Pistolesi, Durability of concrete structures exposed to CaCl2 based de-icing salts, in: V.M. Malhotra (Ed.), Durab. Concr. ACI SP-145, 3rd CANMET/ACI Int. Conf., 1994: pp. 107–120.
8. Y. Farnam, D. Bentz, A. Sakulich, D. Flynn, J. Weiss, Measuring Freeze and Thaw Damage in Mortars Containing De-icing Salt Using a Low-Temperature Longitudinal Guarded Comparative Calorimeter and Acoustic Emission, Adv. Civ. Eng. Mater. 3 (2014) 316–337. doi:10.1520/ACEM20130095.
9. M. Pigeon, M. Regourd, The effects of freeze-thaw cycles on the microstructure of hydration products, Durab. Build. Mater. 4 (1986) 1–19.
10. R.W. Muethel, Investigation of Calcium Hydroxide Depletion as a Cause of Concrete Pavement Deterioration, 1997.
11. S. P. Zhang and L. Zong, Evaluation of Relationship between Water Absorption and Durability of Concrete Materials, Advances in Materials Science and Engineering, Volume 2014 (2014), Article ID 650373, 8 pages,
12. Chanakya Arya, Samira Bioubakhsh, and Perry Vassie, Chloride penetration in concrete subject to Proceedings of the Institution of Civil Engineers - Structures Chloride penetration in concrete subject to wet–dry- Structures and Buildings, wet/dry cycling: influence of moisture content, and Buildings, V.167, Issue 2, February 2014, pp. 94-107.
13. Chanakya Arya, Perry Vassie, and Samira Bioubakhsh, cycling: influence of pore structure, Proceedings of the Institution of Civil Engineers V.167, Issue 6, June 2014, pp. 343-354.http://dx.doi.org/10.1155/2014/650373.
14. T. Zhao , G. Zhu , F. H. Wittmann, and W. Li, On Surface Impregnation of Chloride Contaminated Cement based Materials, Hydrophobe V, 5th International Conference on Water Repellent Treatment of Building Materials Aedificatio Publishers, 311-324 (2008).
15. F. H. Wittmann, T.-J. Zhao, H. Zhan, and Y. Xian, Establishment of an effective chloride barrier in reinforced concrete structures by means of water repellent agents, Proc. Int. Workshop on Life Cycle Management of Coastal Concrete Structures, Nagaoka University, Japan, H. Yokota and T. Shimomura, editors, (2006) 201-208
16. Brandt, A. M., Cement based composites: materials, mechanical properties and performance, Taylor &Francis, 2009.
17. Kurdowski, W., Cement and concrete chemistry, Polish Cement Association, Cracow/ Polish Scientific Publishers (PWN), Warsaw 2010 (in Polish).
18. Hall, C., 1994, Barrier performance of concrete: A review of fluid transport theory, Materials and Structures, 27, 291-306.
19. Saetta, A.V., Scotta, R.V. and Vitaliani, R.V., 1993, Analysis of Chloride Diffusion into Partially Saturated Concrete, ACI Materials Journal, 90-M47.
20. Garboczi, E.J., 1990, Permeability, Diffusivity, and Microstructural Parameters: A Critical Review, Cement and Concrete Research, V.20, pp. 591-601.
21. J. de Vriesl, R.B. Polde and H. Borsje, Durability of Hydrophobic Treatment of Concrete, Water Repellent Treatment of Building Materials Proceedings of Hydrophobe ll ZLirich, September 1998, Aedificatio Publishers pp.77-90.
22. Jacob T, Hermann K (1998) Protection of concrete surfaces: hydrophobic impregnations. Construction y Technology's. (March) 18–23 (only available in Spanish).
23. McCarter WJ (1996) Assessing the protective qualities of treated and untreated concrete surfaces under cyclic wetting and drying. Building Environ 31(6):551–556.
24. Teychenné, D. C, R E Franklin., H. C, Erntroy. (1988). Design of normal concrete mixes, Second edition, BRE.